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The influence of sudden perturbations on trunk muscle activity and intra-abdominal pressure while standing

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Abstract Unexpected ventral and dorsal perturbations and expected, self-induced ventral perturbations were delivered to the trunk by suddenly loading a vest strapped to the torso. Six male subjects were measured for intra-abdominal pressure (IAP) and intra-muscular electromyography of the transversus abdominis (TrA), obliquus internus abdominis (OI), obliquus externus abdominis (OE) and rectus abdominis (RA) muscles. Erector spinae (ES) activity was recorded using surface electromyography. Displacements of the trunk and head were registered using a video-based system. Unexpected ventral loading produced activity in TrA, OI, OE and RA, and an IAP increase well in advance of activity from ES. Expected ventral loading produced pre-activation of all muscles and an increased IAP prior to the perturbation. The TrA was always the first muscle active in both the unexpected and self-loading conditions. Of the two ventral loading conditions, forward displacement of the trunk was significantly reduced during the self-loading. Unexpected dorsal loading produced coincident activation of TrA, OI, OE, RA and ES. These results indicate a response of the trunk muscles to sudden expected and unexpected ventral loadings other than the anticipated immediate extensor torque production through ES activation. It is suggested that the increase in IAP is a mechanism designed to improve the stability of the trunk through a stiffening of the whole segment.

Key words Electromyography · Abdominal Peturbation · Balance · Pressure · Human

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Introduction

One of the most widely used methods for studying neural mechanisms in balance control is to disturb the equilibrium of the body. This is most often achieved by delivering controlled perturbations and observing muscle reactions of various segments and changes in location of the centre of mass and centre of pressure of the body. As the trunk is the segment of the body which comprises the greatest mass, its control during balance disturbances is an important task that the central nervous system must accomplish. If a sudden perturbation accelerates the trunk in any direction, or the total mass of the trunk is increased by the addition, or carrying, of a load, a greater demand will be placed upon the central nervous system to restore balance and minimize the possibility of injury to the spine and its surrounding structures.

The most common type of perturbation used for investigating both normal and pathological balance control has been the unexpected movement of a support surface while standing (Gurfinkel et al. 1974; Nashner 1976; Diener et al. 1983; Allum and Pflatz 1985). This type of perturbation is often delivered unawares (involuntary) to the subject and has mostly shown robust patterns of leg muscle activity which are specific to both the movement direction and magnitude of the platform. Short-latency activation of muscles from the trunk and neck has also been observed during these standing (foot rotations and translations; Keshner et al. 1988; Woollacott et al. 1988) and additionally sitting (trunk translations and rotations; Hirschfeld and Forssberg 1992) perturbations. The observed reflex activation of muscles not only in the perturbed segment but also throughout the body indicates the complex nature and general integration of the neural control required to compensate for balance disturbances. This complexity is further exemplified by anticipatory adjustments that are made at a conscious and subconscious level prior to known perturbations (Bouisset and Zattara 1990; for review see Massion 1992). If the direction of the perturbation is

known, adjustment of the initial posture is performed along with a general joint stiffening, accomplished through coactivation of flexor and extensor muscle groups. Similar adjustments are commonly seen when perturbations to balance are produced voluntarily by intended arm, leg and trunk movements (cf. Lestienne and Gurfinkel 1988). In such cases, feed-forward activation of muscles are pre-programmed to minimize ensuing balance disturbances. Back and neck extensor muscles activated prior to a voluntary arm rise (Belen'kii et al. 1967; Bouisset and Zattara 1981; Cordo and Nashner 1982; Gurfinkel et al. 1988) and ankle extensors activated prior to back extensors during trunk extension (Oddsson 1989) and toe rises (Lestienne and Gurfinkel 1988) are such examples.

The effects of involuntary perturbations to the trunk are less well known than the feed-forward preparations made by the central nervous system during rapid and slow voluntary trunk flexions and extensions (cf. Oddsson 1990). In a study by Carlson et al. (1981) unexpected perturbations to the trunk were produced by unloading and loading the dorsal and ventral sides of the thorax, respectively. Strong activations of stretched muscles after the disturbance reflected a neural mechanism designed to return the trunk to upright and regain balance. Paradoxically, concomitant activation of muscles on the ventral, non-stretched side also took place. It was suggested that the activity of the observed ventro-lateral abdominal muscle (obliquus externus, OE) helped in stabilizing the trunk through its ability to increase intra-abdominal pressure (IAP), a response that is often seen during lifting, running, jumping and other such tasks (cf. Grillner et al. 1978; Kumar 1980; Stålhammar et al. 1987).

It has been shown in earlier studies that it is not only OE that is active in the development of an increased IAP (Cresswell et al. 1992). Two other muscles of the four that comprise the ventro-lateral abdominal wall (transversus abdominis, TrA, and obliquus internus, OI) have a greater ability to compress the abdominal contents and thereby raise IAP. The activation of OI and OE and the associated pressure increase have been previously observed in many locomotive and postural tasks (Grillner et al. 1978; Cresswell et al. 1992), while intra-muscular myographic recordings from TrA have more recently shown the importance of this muscle in increasing IAP (Cresswell et al. 1992; Cresswell 1993). The increase in IAP appears often to occur as both a reflex response to fast, high-loading situations and a conscious act prior to known lifting and forcible tasks. Its development therefore has been thought to be an important factor in stabilizing the trunk and/or unloading the lumbar spine (cf. Bartelink 1957; Andersson et al. 1976; Thomson 1988)

The main objective of this study was to clarify whether perturbations delivered to the trunk would display a neural strategy where early activation of the non-stretched muscles of the ventro-lateral abdominal wall and an increase in IAP would occur. In addition, voluntary perturbations to the ventral side of the trunk were used to determine whether IAP was increased prior to the perturbation in a feed-forward manner.

Materials and methods

Subjects

Six men voluntarily participated in this study. The means ± SD for age, height and mass were 24 ± 2 years, 1.81 ± 0.03 m and 79 ± 3 kg, respectively. All subjects were in good health, routinely active and had no history of back pain. The project was approved by the Ethics Committee of the Karolinska Institute and each subject gave his informed consent to participate.

Experimental design

From a relaxed standing position, sudden ventral or dorsal loading was applied to the trunk by way of a molded plastic vest strapped to the torso (Carlson et al. 1981). A non-elastic string with a 5-kg load was attached to horizontal bars that extended 12 cm ventrally and dorsally from the vest, respectively (Fig. 1 A). Perturbations were delivered by dropping the weight 25 cm prior to the string tightening. "Front-loading" was achieved by unexpectedly dropping the weight ventrally; "self-loading" required the subjects to ventrally drop the weight themselves; while "back-loading" was unexpected dorsal loading. Vision was blocked downwards by a visor worn about the neck.

Movement recordings

Displacements of the hip, shoulder and head were registered in the sagittal plane using a video-based analysis system (APAS; Ariel Life Systems, USA). Light-reflective markers were applied over the right trochanter major, acromion process and fossa temporalis for easy identification during manual digitizing (60 Hz). Angular displacements of the trunk and head were calculated with their

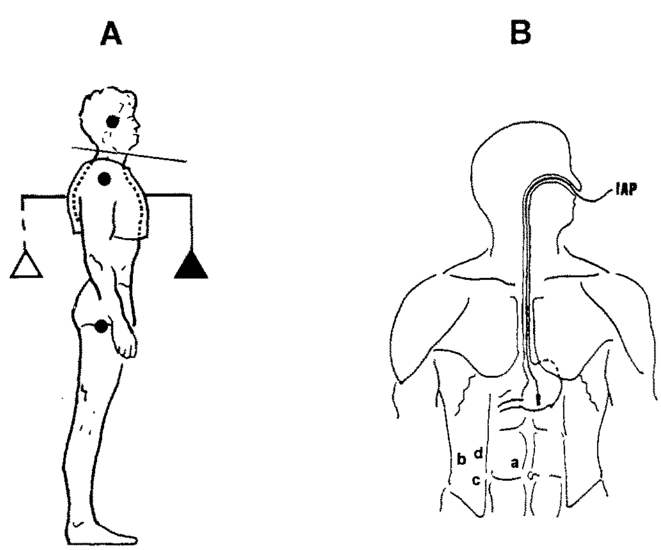

Fig. 1 **A** A subject, perturbation vest with 5 kg weight(s), visor restricting the subject's vision downwards and light-reflective markers to define the trunk and head segments. **B** Location of the intra-abdominal pressure (*IAP*) transducer in the gastric ventricle and intra-muscular electromyography electrode locations in : *a*, rectus abdominis; *b*, obliquus externus; *c*, obliquus internus; and *d*, transversus abdominis